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The importance of site investigation in the construction industry: a lesson to be taught to every graduate civil and structural engineer

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ABSTRACT: Risks inherent within the ground are attributed to significant cost and time overruns on construction projects. Instead of addressing such risks by a comprehensive site investigation, they are often ignored as an unnecessary cost. Savings on the site investigation budget generally prove to be false economies. Moreover, there is a lack of clear guidance on spending to procure adequate site investigation works as a proportion of the overall contract sum of a project. *BRE Digest 322: Site Investigation for Low-Rise Building* recommends that expenditure on ground investigation should be a minimum of 0.2% of the total project cost [1]. The focus of this article has been to investigate the accuracy of this figure by undertaking a case study, whereby a virtual project was designed based on arbitrary decisions where its overall cost of construction was priced and compared to the cost of its site investigation. The results of this article proved that adequate site investigations for low-rise buildings should in fact be a minimum of 0.42% of the cost of a project. This message must be given repeatedly to all civil and structural engineering students worldwide.

INTRODUCTION

Ground-related factors have often been the origin of contractual claims with significant time and cost overruns on both large and small construction projects. According to European statistics, between 80% and 85% of all building failures and damages are related to unforeseen and unfavourable ground conditions. Without adequate site investigation, clients are always exposed to the risk of costly delays, redesign and late project delivery arising out of unforeseen ground conditions; *You pay for a ground investigation whether you have one or no*t [2].

In 1994, the Latham Report stated that risk *...can be managed, minimised, shared, transferred or accepted; it cannot be ignored* [3]. Unfortunately, when it comes to the risk of unforeseen ground conditions, ignorance on behalf of both the contractor and employer often seems commonplace.

As unforeseen ground conditions represent a huge area of risk, a construction contract either has to allocate the risk to a single party or distribute it between the parties. The traditional method of controlling such risks has been through the use of thorough site investigation and competent geotechnical design, aiming to produce a robust scheme, well-matched to the expected ground conditions.

Figure 1: Collapsed foundations and associated cracked mortar within brick and block work of residential structures as a result of unforeseen ground conditions.

Figure 2: Flooded section of the tunnel due to a lack of geotechnical expertise.

HISTORY OF CONSTRUCTION PROJECTS WITH INADEQUATE SITE INVESTIGATION

Highways Projects, UK

In 1992, a report compiled by the government showed that the final outturn cost above tender values for completed highway contracts sat at 28%. Further analysis of 17 of these contracts showed 44% of the cost increase was attributable to earthworks and unforeseen ground conditions [4]. Similarly, the Department of the Environment, Transport and the Regions (DETR) annual report, highlighted that the seven largest road projects were some £516 million over budget, due mainly to unforeseen ground conditions [5]. This equated to an over-spend, which accounted for a massive 63% increase in projected expenditure [6].

Five of the schemes included within the DETR analysis were also revealed to be between one to five years behind schedule. The biggest cost overrun at £184 million on the M66 Manchester ring road was also found to suffer from delays to the contract programme by 35 to 46 weeks. In response to claims totalling £30 million, Agency project manager confirmed that *All contracts run through difficult urban areas and faced previously unknown ground factors* [6].

Hallandsås Tunnel Project, Sweden

The Hallandsås tunnel project in Sweden involved the construction of two 8.6 km long railway tunnels through rock which were designed to increase the capacity of Sweden's west coast railway. Initial costs, however, escalated from the original budget of £440 million to £840 million at 2008 prices as a result of flawed construction processes based on poor geotechnical expertise [7]. Construction of the tunnel began in 1992 through the Hallandsås Ridge, which is a bedrock horst that was formed millions of years ago. Although the most common types of rock, gneiss and amphibolites, with granite and diabase found in smaller quantities were of excellent quality, sections of the ridge were exceptionally cracked and severely disintegrated containing large volumes of water.

A Swedish contractor, Kraftbyggarna, commenced the project but left with only 3 km completed when its open tunnel boring machine proved unable to deal with the disintegrated rock in 1995. Skanska took over as the contractor in 1996, and in an attempt to make up for lost time, opened an audit in the centre of the ridge. However, this only resulted in further large volumes of water leaking into the northern tunnel. A chemical sealant, Rhoca Gil, was discontinued in 1997 after it was discovered that it had run into the streams, which the tunnel water released into contaminating them with acrylamide. As a consequence, the tunnel construction was brought to a halt with just one third completed.

In 2004, work recommenced following a seven year hiatus to seal the tunnels with a waterproof lining. The revised, bored method performed satisfactorily, but progress was slower than had been anticipated, primarily due to unforeseen ground and water conditions. As at April 2009, progress was measured at 59% complete with rail traffic estimated to commence in 2015.

The Big Dig, Boston, USA

The main cause cited for the £900m overrun on the Boston Artery project, or *Big Dig* as it became known, has been unforeseen ground conditions. The scheme, which has been one of the most significant urban transport schemes in the world was intended to relieve road traffic congestion through the heart of the city. Previously, the traffic congestion had been estimated to cost motorists in excess of £300 million every year [8].

The scale of the project involved using cut and cover tunnels to replace huge sections of elevated highway, jacking tunnels beneath railway lines and immersing prefabricated tubular tunnels to cross the harbour area, completely reconfiguring the road layout. In all, some 10,000,000 m^3 of material was excavated. A large area of the natural harbour, which was originally a series of inlets, had previously been backfilled to facilitate the expansion of Boston. As a result, a highly variable mix of fill, sand, silt and peat overlay the Boston Blue Clay, which softens with depth. Some of the fill contained a variety of construction materials including concrete, steel, timber and granite blocks. To compound these adverse ground conditions, a high water table exists with groundwater two to three meters below the surface. Some of the obstructions in the fill did not come to light until construction had begun. The client, a partnership between the Massachusetts Turnpike Authority and the Massachusetts Port Authority, was ordered to pay $29 million for 236 lost days of construction.

AIM OF THIS WORK

A case study was carried out in order to determine and compare the proportionate level of spend required for an adequate site investigation for a construction project. This spend/cost was, then, compared to the spend/cost of the construction of the actual project in the same site. Costs of the site investigation were based on a virtual site designed by the author of this project. Items included within the Bill of Quantities (UK) for the site investigation, were compiled with the advice of a site investigation contracting company.

The *virtual construction* of the actual project chosen for this case study, was also constructed in the same *virtual* site as the site investigation. This comprised the construction of a building containing a 25 meter swimming pool with dry facilities. There was also a requirement for associated car parking within the site. This particular project was chosen because it demonstrates challenges faced by professionals within the built and natural environment on an architectural, structural, environmental and geotechnical level [9].

The site was assumed to be a brown-field site with easy access, 60 m x 100 m, in a city centre location in the central belt of Scotland, abounded by adjoining sites to the east and west and by a river and public road to the north and south, respectively. The anticipated site conditions were assumed to comprise a 5 m layer of alluvial deposits above sandstone [10]. The following quantities detailed in Figure 4 have been obtained from a take-off from a drawing:

Figure 3: Catering for a mix of leisure, teaching and fitness swimming.

Building footprint	760	m^2
Hardstanding around building	794	m^2
Pavement	2,116	m^2
Car parking	1,843	m^2
Footpath	61	m^2
Landscaped area	426	m^2
Total	6,000	m^2

Figure 4: Quantities relating to case study.

PRICE INDICES

Cost planning of the building and infrastructure as proposed by the case study has been carried out by drawing on data supplied by the building cost information service (BCIS) (of the Royal Institution of Chartered Surveyors) [11]. The BCIS tender price indices (TPI), published quarterly on a 1985 mean for base value 100, measure trends of pricing levels tendered for by contractors for schemes, which have been let on a lump sum basis on bills of quantities. This allows the BCIS to provide standard adjustments to be applied to a project index to remove anomalies in index levels as a result of works being carried out in different regions and calendar quarters [11]. The BCIS All-in TPI, which has been used in this case study comprises new build work throughout the United Kingdom including the public, private and housing sectors.

CONSTRUCTION OF THE SWIMMING POOL

Swimming as a leisure pursuit depends greatly on the availability of high quality infrastructure. In recent years, existing stock in the public sector has been viewed as somewhat of a liability through maintenance problems and in many cases has been branded unfit for purpose [12].

COST DRIVERS

In terms of public-sector leisure facility buildings, swimming pools are amongst the dearest for construction and maintenance. Crucially, the areas where a larger part of the budget is spent are in the substructure, pool tank, mechanical services, finishes and the roof. These are often very complex to value-engineer, as performance has to be of such a high standard to negate operational problems. In attempting to provide a solution, which is cost-effective, the following have been identified as being important: pool size is the key driver which in turn determines the hall size, changing rooms, etc. The majority of the expensive building work is connected with the pool, so the pool size will have most significant bearing on the overall cost.

Generally, pools require depths ranging from 1 m to 1.2 m for leisure purposes and are required to be 2 m deep for swimming at a competitive level. Greater depths will consequently require a bigger tank, greater filtration and heating plant. A high water table in the site's ground conditions may require ground anchoring of the pool tank should water pressure become too high [13].

Cost of Construction for Building Itself

By applying the changes to the quantities, which have been detailed to the original cost model, the revised construction cost for the building only is £7,143,204. The relevant location factor provided by the cost model to be used for adjustment for Scotland, UK, is 0.83 and the tender price indices for Q1 in 2006 and Q1 in 2010 are 228 and 215, respectively [9]. This brings the construction cost of the proposed two-storey low-rise building incorporating a 25 m swimming pool with dry facilities as proposed in the case study to £5,590,670.

$$\text{£}7{,}143{,}024 \quad \text{x} \quad 0.83 \quad \text{x} \quad \frac{215}{228} \quad = \quad \text{£}5{,}590{,}670$$

CONSTRUCTION OF THE SURROUNDING INFRASTRUCTURE

The infrastructure requirements of the project are primarily focussed on the provision of a car parking facility for the users of the building. In addition, considerations have been given to pavements, kerbing, soft landscaping, street furniture and external drainage within the site.

Car Park Configuration

Car parks in city centre locations have recently found it challenging to meet the standards set by out of town retail developments as a result of higher land costs and the impact of busier traffic in the surrounding street networks. The configuration of a car park will ultimately be determined by the dimensions of the site, the overall size of the car park and the car park's intended use.

The design of the car park in the case study is based on providing parking to 80 vehicles in parking bays with dimensions of 4.8 m x 2.4 m. These dimensions are a standard planning model accommodating 95% of all passenger vehicles licensed in the UK [14].

Pavements

Pavement construction is required both for access to emergency services to the perimeter of the building and for ingress from and egress to the street to the south of the site. The pavements have been designed to a carriageway construction specification of dense bitumen macadam, 200 mm thick, and sub base.

Concrete slabs have to be laid to provide a hard standing around the building, while brick pavers need to be laid to footpaths in the car park. As a health and safety consideration to pedestrians, 24 no. bollards must be installed on the footpaths and hard standing areas. Road kerbs measuring 10" by 5" are required for a length of 687 m relating to the aggregate length of all borders of pavements and car parking.

Soft Landscaping and Street Furniture

The limit of the car park to the north and the perimeter of the northern end of the site are to be soft landscaped. This is to be carried out by initial cultivation, topped off by a 100 mm layer of imported topsoil and shrubs planted covering half of the landscaped area. Other items of street furniture to be included are the provision of ten litter bins and ten cycle racks.

External Drainage

Although the cost plan for the building provides for internal drainage, no such provision is made for external drainage. The cost plan allows for separate foul and surface water drains running the entire 100 m length of the site to the existing drainage in the carriageway to the south of the site. With an allowance made for a manhole every 25 m for each system, the cost plan allows for an aggregate quantity of eight.

Cost Plan Data for Building Infrastructure

A cost plan has been prepared for the proposed infrastructure based on data obtained from a cost model, prepared by Davis Langdon [12], which appeared in the 17th issue of *Building Magazine* during the 2nd quarter of 2006, based on price levels, which were current at the time for south-east England. Calculations based on this data gives a cost of infrastructure of £310,945 at those base levels. The relevant location factor provided by the cost model to be used for adjustment for Scotland is 0.92 and the tender price indices for Q2 in 2006 and Q1 in 2010 are 231 and 215 respectively. This brings the value of the infrastructure associated with the building as proposed in the case study to £266,256.

$$\pounds 310{,}945 \quad \times \quad 0.92 \quad \times \quad \frac{215}{231} = \pounds 266{,}256$$

COST OF THE ENTIRE PROJECT

The overall cost of construction of the project works out to be: £5,856,926. (i.e. 5,590,670 + 266,256 = 5,856,926).

Cost of Site Investigation

The site is in a city centre location. Many European cities are situated on navigable rivers where earlier civilisations benefited from access to trade, water, fishing and arable land.

Geological Considerations

The geological significance of rivers is that they transport the majority of sediment or alluvium, with debris of a coarser nature rolled along river-beds and finer particles carried in suspension. Alluvial deposition from rivers will commonly contain layers of compressible soft silts and clays and organic matter such as peat. The site is assumed to be sitting on an average of 5 m of alluvial deposits which, in turn, sits on a layer of sandstone [15].

Bill of Quantities for the Site Investigation

For the purposes of the case study, a bill of quantities was prepared, which dealt solely with the site investigation as a separate contract. Based on the method of measurement provided by CESMM3, the bill was prepared using quantities obtained from the in-situ site conditions [16]. The bill was divided into the following sections:

Section A - General items and provisions
Section B - Exploratory holes
Section C - Borehole sampling
Section D - In situ testing
Section E - Instrumentation and monitoring
Section F - Geotechnical laboratory testing

Cost of the Site Investigation

The bill of quantities prepared for the site investigation, using current rates, was able to give a total cost of the site investigation of £24,537.50. This relates to 0.42% of the overall cost of construction for the project calculated to be £5,856,926.

$$\frac{\pounds 24{,}537.50}{\pounds 5{,}856{,}926.00} \quad \times \quad 100\% \quad = \quad 0.42\%$$

CONCLUSIONS AND RECOMMENDATIONS

This project was carried out to investigate the high incidence of cost overruns and programme delays in construction and civil engineering as a result of unforeseen ground conditions. During the course of the research, it has been demonstrated that many employers and their consultants do not fully appreciate the inherent risks within the ground at inception stage.

The focus of this research was placed on finding an appropriate level of spend for site investigation works, which were considered adequate for their intended purpose. There exists a lack of clear guidance on spending on site investigation works as a proportion of the overall contract sum of a project. However, *BRE Digest 322: Site Investigation for Low-Rise Building: Procurement*, recommends that expenditure on ground investigation should be a minimum of 0.2% of the cost of a project.

The case study undertaken was designed to test the accuracy of this figure by proposing such a low rise building, with assumed site conditions considered typical for a brown field site within a city centre location, which could be accurately cost planned and compared with reliable cost data obtained by an approach to industry. In addition, the technique of cost planning of a project by using an elemental cost analysis is regarded as being very reliable compared to other techniques.

The findings of the case study showed that although the figure of 0.2% is the minimal recommendation, it is nonetheless insufficient. This project, which has been designed under the advice of ground investigation specialists, has proved that a minimal figure for an adequate site investigation would be 0.42% of the total construction costs of the project. This figure is in keeping with other percentage levels of spend identified within the literature review, which suggests that although the figures for site investigations in the UK are not reported, published data suggests an average value of 0.5% of the contract cost. It is also consistent with the assertion within the literature review that doubling the ground investigation budget will generally add less than 1% to the project cost. However, unforeseen ground conditions attributable to inadequate investigation can, and frequently do, increase costs of projects by 10% or more. In other words, you pay for a site investigation whether you have one or not.

Contrary to site investigation being viewed upon as an unnecessary cost for a report, which may or may not tell the employer what they want to hear, employers and their consultants must appreciate that it provides a cost effective function by detecting, assessing and minimising risks. In the absence of a site investigation, which has not been suitably procured, various hidden dangers that lie beneath the site cannot possibly be known.

It is the recommendation of this article that all civil/structural engineering students of all universities, worldwide, who may be acting as future consultants within the design team, should be aware of the risks, which are inherent within the ground. In attempting to minimise such risks to the client, they should make provision for acceptable levels of spend to procure adequate site investigation. The figure put forward is a minimum of 0.42% of the overall construction cost of the project.

Site investigation as a subject, is only taught for as little as a couple of weeks in the 3rd year of most civil/structural courses in most universities worldwide (in some institutions it is not even taught at all). Site investigation must be taught in all civil/structural engineering courses at all levels and in all universities worldwide. The way to teach it is to use extensive short video clips and ensure students visit proposed construction sites. Students must gain first-hand experience in-situ.

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